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Bayesian analysis of the effectiveness of condoms uses as an intervention method against HIV among sex workers and its impact on the HIV prevalence rate in Livingstone, Zambia

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ABSTRACT

Acquired immune deficiency syndrome (AIDS) is the leading cause of death among adolescents and adults in Sub-Sahara Africa. The rollout of HIV infections in Zambia is faced with the challenges of increasing rate of infections, although the number of intervention programs, government has put in place during the last decade intended to lower the infection rate. The high rate of HIV infection among youth in Africa has prompted both national and international attention. Zambia is experiencing a generalized Human immune virus (HIV) epidemic, with a national HIV prevalence rate of 12.7 percent among adults ages 15 to 49. In Zambia, some intervention programmes which were seen as the primary way of decreasing this rate were put in place to mitigate against new infections. However, the effectiveness of these interventions has not been systematically evaluated. In this article, I describe condom use among sex workers as an intervention program in Livingstone, Zambia, whose primary goal is to reduce new HIV and STI infections and assess their impact in reducing new HIV infection rate. Results obtained indicated that despite this intervention program, it was observed that on average probability of sex workers is 0.5755 (58%) use condoms, with a mean probability of 0.67658 (68%) males use condoms and a mean of 0.4512 (45%) females use condoms when having sex. This percentage use of condoms is not active and has made no positive impact in reducing HIV prevalence rate in Livingstone and even at national level. As at present Zambia has an HIV prevalence of 14.5% distributed among both males and females and Southern Province has an HIV prevalence of 14.7% with Livingstone showing a figure in HIV infection rates of 23.5 percent. In Zambia, HIV prevalence rate has made little progress in the last decade, despite intervention programs put in place as records show a 12.8% adult prevalence in 2007 compared to a 12.4% prevalence rate in 2016.

Keywords: Prevalence rate, HIV infections, condoms, sex workers, interventions programmes.

1. INTRODUCTION

Transmission of human immunodeficiency virus (HIV) is a significant challenge in Zambia. Over 1.2 million people were living with HIV with a prevalence rate of 12.4% and 59 00 new infections in 2016, primarily acquired through sexual transmission [15]. Most new infections occur in people who do not use condoms or use them inconsistently or incorrectly [13]. Although 1.2 million people live with HIV in Zambia and 67% are in ARV care the remainder do not know their status of their sexual partners [13]. Regardless of individuals' awareness of HIV status, it is estimated that the correct and consistent use of condoms is effective in reduces the risk of sexual transmission of HIV infections in sex workers, and heterosexual couples [9][4][5]. The use of condoms as a prevention intervention is a common measure of assessing changes in HIV related behaviour. However, there are no existing

standard methods of measuring the effectiveness of condom use [6][1][8]. Lack of proper risk perception on use of condoms impedes women's ability to negotiate condom use with their partners [2]. Inconsistency use of use of a condom or no use of a condom or lack of trust is due to trust in the reliability of condoms to protect individuals [3][7]. Many people use condoms during sexual contact with casual partners or multiple partners than with steady partners [12]. The other barriers to condom use our attitudes, beliefs, decrease in sexual pleasure, religious beliefs, and other cultural beliefs [11]. Condoms are efficacy and useful in the prevention of STI, HIV, and pregnancy [10]. The number of sex workers in Zambia is disputed, as is the HIV prevalence among this population, with studies reporting vastly different statistics. Studies conducted in Zambia in 2015 found out that female sex workers and male long-distance truck drivers had HIV prevalence rate among female sex workers was 56.4%[13][14]. However, prevalence among female sex workers ranged from 46% in Livingstone, and these sex workers have multiple partners and only 44% use condoms with non-paying clients and 78% use condoms with paying clients [13]. Despite the distribution of free condoms in health facilities in Zambia, the use of condoms is quite low with only 29% of men and women who has multiple partners use condoms. On average only 47% of the young people in Zambia are more likely to use condoms with non-regular partners [13].

2. MATERIALS AND METHODS

The study design was that condoms were placed in bathrooms of a night spot where sex workers are patronizing in the evening where they do their businesses. A pack of 100 condoms was placed in bathrooms for both male and female. For females and extra 50 female condoms were added. The aims are to assess knowledge and awareness that condom use during sexual intercourse may save them from contracting STI, prevent unwanted pregnancies and above all protect them from contracting HIV. This survey was done under some assumptions:

1. That an individual will only take a condom only when he/she is likely to have sexual intercourse,
2. Each will only take one condom for an encounter, as carrying more than one would mean taking an extra condom home, which would bring problems if married,
3. Correct use of condoms was assumed,
4. Sex workers do not guarantee consistency use of condoms in this study,
5. Use of a condom is assumed to be voluntary.

Every morning the number of condoms collected were counted from, and this formed the data which was used for analysis in this survey. In assessing the use of condoms two Bayesian methods where adopted: The first is to calculate the probability of awareness that a condom can be used as a preventive method against HIV infection. The data were grouped into four weeks to check which time of the month is condom favourite. The results indicate overall picture and reported by gender. To do this, an individual will decide to take a condom or not. This means evidence can be analysed using the Beta-Binomial hierarchical model in which posterior distributed is calculated which accounts for uncertainties.

2.1 Framework:

Let y_i be an observation and ϑ_i a parameter governing the data generating process y_i. Assume that ϑ_i is created exchangeable from a standard population with distribution governed by a hyper parameter ϕ, ϑ_i and ϕ are random variable parameters, the Bayesian hierarchical model is:

Stage I: The likelihood of I is $p(y_i \mid \vartheta_i, \phi)$, prior distribution $p(\vartheta_i, \phi)$ and the likelihood depends on ϕ only through ϑ_i. Therefore, prior distribution in I is

$$p(y_i \mid \vartheta_i, \phi) = p(\vartheta_i \mid \phi)\, p(\phi) \qquad (1)$$

(Using Bayes' Theorem) With ϕ as a hyper parameter with hyperprior distribution $p(\vartheta)$. Therefore, the posterior distribution is proportional to the prior times the likelihood function.

$$p(\phi, \vartheta_i \mid y) \propto p(y_i \mid \vartheta_i, \phi)\, p(\vartheta_i \mid \phi)$$

Stage II: The joint posterior distribution

$$p(\vartheta, \phi \mid y) = \frac{p(y \mid \vartheta, \phi)\, p(\vartheta, \phi)}{p(y)} = \frac{p(y \mid \vartheta)\, p(\vartheta \mid \phi)\, p(\phi)}{p(y)}, \qquad (2)$$

Where using Bayes rule $p(y)$ can be expressed as:

$$p(y) = \frac{p(y \mid \vartheta)}{p(\vartheta)} \tag{3}$$

Which is a conditional probability, to give

$$p(y) = \int_{\vartheta \in \Theta} p(y \mid \vartheta) p(\vartheta) d\vartheta, \tag{4}$$

The use of the hyperprior provides more information to make more accurate opinions on the behavior of the parameter.

Stage III: The posterior distribution is given by:

$$p(\vartheta, \phi, x \mid y) = \frac{p(y \mid \vartheta) p(\vartheta \mid \phi) p(\phi \mid x) p(x)}{p(y)}. \tag{5}$$

The second approach is to calculate the relative risks for gender in the use of condoms using a Poison distribution as a likelihood function and beta prior and gamma distribution as a hyperprior.

2.2 Cox Proportional Hazards Model

The Cox, a proportional hazards model, is one of the most useful models to assess risks. It is defined as

$$h(t, X) = h_0(t) e^{\sum_{i=1}^{i=p} \beta_i X_i}, \tag{6}$$

Where $h_0(t)$ is the baseline hazard function, the β_i y are unknown regression parameters, and the X_i have known covariates or independent variables. It should be noted that the baseline hazard function is a function of time only, but that the covariates are not functions of *t*. Recall that the regression function is defined regarding the hazard function.

$$h(t) = \frac{\lim_{\Delta t \to \infty} P(t \le T < t + \Delta t | T \ge t)}{\Delta t}, \tag{7}$$

Which in turn is related to the survival function *S* (*t*) by the relation to providing a suitable Bayesian analysis

$$h(t) = \frac{[{dS(t)}/{dt}]}{S(t)} \tag{8}$$

Besides, the survival function is

$$S(t) = P(T > t) \tag{9}$$

In which *T* denotes the survival time of a subject. In survival analysis, the Cox regression model is expressed as a hazard, whereas the usual way to express a regression is more directly using *T* as a function of unknown regression coefficients. One reason the Cox model is so popular is its versatility. With the Cox model, the time variable *T* is not assumed to have a specific distribution; thus, the model is quite general in that it can be applied in a large variety of time to event studies. Also, note that the *p* covariates $X = (X_1, X_2, ..., X_p)$ are not functions of *t*; however, there are cases where one would have time-dependent covariates, in which case, a more general Cox model is appropriate. The most critical assumption of the Cox model is to compare the risks of two or more groups; the corresponding hazard functions must be proportional. The parameter of risk analysis is called the hazard ratio.

$$HR = \frac{h(t, X')}{h(t, X)} \tag{10}$$

Between two individuals, one with the covariate measurements X* and the other with the measurement *X*, on the p covariates.

$$HR = e^{\sum_{i=1}^{i=p} \beta_i (X_i'^{*} - X_i)} \tag{11}$$

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Where both X^* an X is known. In Bayesian perspective, the HR hazard ratio (Equation 11) is an unknown parameter because it depends on p unknown parameters.

$$\beta = (\beta_1, \beta_2, ..., \beta_p) \tag{12}$$

Note that the model separates the effect of time from the effect of the covariates. Taking logs, we find that the proportional hazards model is a simple additive model for the log of the hazard, with

$$\log \lambda_i(t|x_i) = \alpha_o(t) + x_i'\beta, \tag{13}$$

Where $\alpha_o(t) = \log \lambda_o(t)$ is the log of the baseline hazard? As in all additive models, it is assumed that the effect of the covariates x is the same at all times t. The similarity between this expression and a standard analysis of covariance model with parallel lines should not go unnoticed. Returning to Equation 7.10, we can integrate both sides from 0 to t to obtain the cumulative hazards.

$$\Lambda_i(t|x_i) = \Lambda_o(t)\exp\{x_i'\beta\} \tag{14}$$

Which are also proportional. Changing signs and exponentiation, we obtain the survivor functions.

$$S_i(t|x_i) = S_o(t)\exp\{x_i'\beta\} \tag{15}$$

Where $S_o(t) = \exp\{-\Lambda_o(t)\}$ is a baseline survival function? Thus, the effect of the covariate values x_i on the survivor function is to raise it to a power given by the relative risk $\exp\{x_i'\beta\}$.

Thus, the Bayesian must specify a prior distribution for β, then, through Bayes' theorem, determine the posterior distribution of β and any function of β such as the hazard ratio. Here, the hazard ratio, consider the combinations of HIV patients, where males and females with one covariate, where X* is males and X is female. The hazard ratio (Equation 11) then reduces to

$$HR = e^{\beta}, \tag{16}$$

In which one individual is a patient from the males and the other a patient from females. Thus, Equation 16 expresses the hazard ratio as an effect of risks. The estimate of β *here is* an estimate of the hazard ratio, that means the posterior distribution of β, implies the posterior distribution of HR. If $\beta = 1$, this model reduces to the exponential and has constant risk over time. If $\beta > 1$, then the risk increases over time. If $\beta < 1$, then the risk decreases over time. However, In using the Bayesian methods Markov Chains Monte Carlo (MCMC) algorithm using Gibbs sampling was used, convergence diagnosis was made using visual graphical methods Brooks, Gelman, and Rubin plots, History trace, density and autocorrelations where used which guaranteed convergence of chains to a limit.

3. RESULTS AND DISCUSSION

The Bugs code 3.1 below gives the syntax used in calculating the posterior distributions of the probability of knowledge and awareness of condoms as a preventive method of HIV infections. The computation was done using an MCMC algorithm using GIBBS sampling.

Bugs code 3.1 Condom use overall

```
model {
a~ dgamma(0.01,0.03)
b~ dgamma (0.01,0.01)
for (i in 1:k) {
theta[i]~ dbeta (0.5,0.5)
y[i] ~ dbin(theta[i], n[i])
}
}
```

Data list(k=4,

n=c(1400, 1400, 1800, 1800), y=c(780, 827, 959, 1119))

initial values list (a=0.5, b= 0.5)

Figure 3.1 below shows the convergence of chains to a limit. It can be seen that the chains gives a plot which looks like a fat caterpillar indicating that the chains has stabilised to a limit.

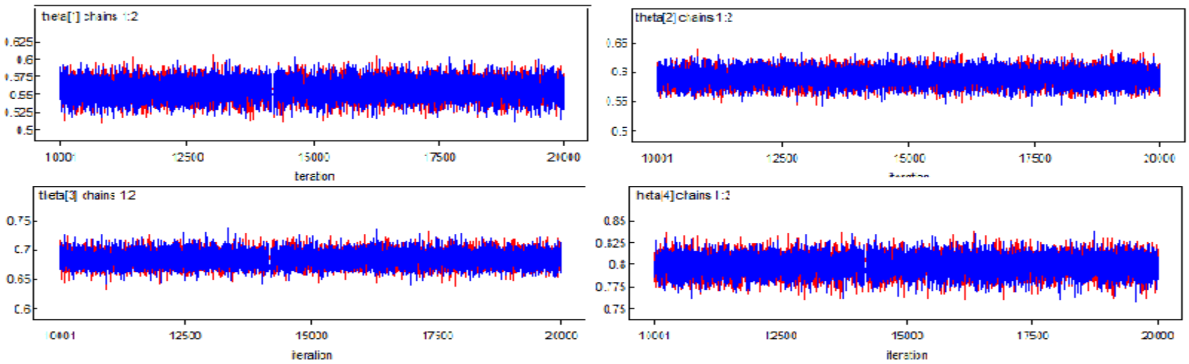

Figure 3.1 Convergence diagnosis of chains

BGR plots in figure 3.2 below indicate that the chains have converged to a limit. When converges is achieved the graph should stabilize at about 1, and this is what figure 2 below shows.

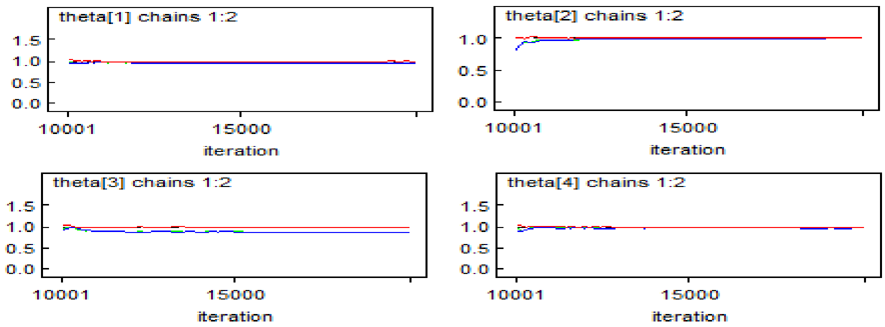

Figure3.2 Brooks, Gelman and Rubin convergence diagnosis plots

The autocorrelations shown in figure 3.3 below shows that the data used is not time dependence. It can be observed that all parameters ha autocorrelation zero, means data used is independent of time.

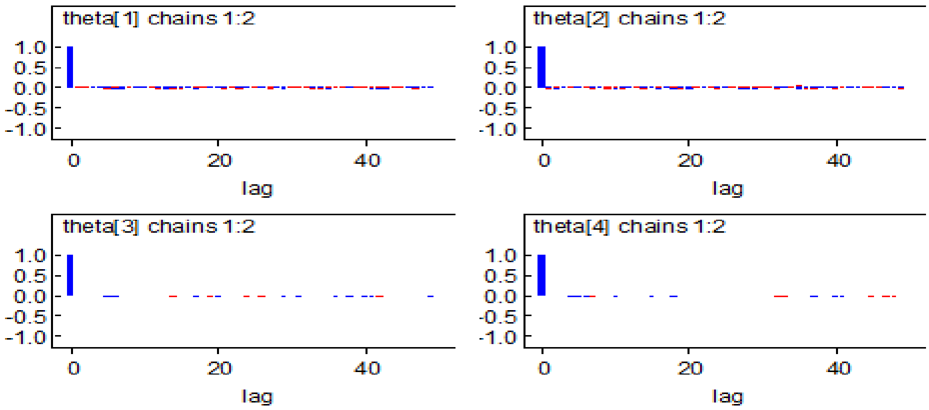

Figure 3.3 Autocorrelation of chains

From table 3.1 below it can be observed that the probability of sex workers using condoms in week 1 is 0.5571 with a mean of 0.5571 and a credible interval of (0.5512, 0.5828). While that of week 2 of the month the probability of sex workers using a condom is 0.5907. The probability of sex workers using condoms during the last week of the month is 0.6216 with a median of

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0.6217 with a credible interval of (0.5991, 0.6438). This shows that the last weeks of the month assumed to be the time when people are paid, 62% of sex workers use a condom compared to week 3 when only 53% of sex workers use condoms.

Table 3.1 Summary statistics of overall use of condoms

Node	Mean	SD	MC_Error	Val2.5pc	Median	Val97.5pc	Start	Sample
Theta[1]	0.5571	0.01325	8.949E-5	0.5312	0.5571	0.5828	10001	20000
Theta[2]	0.5907	0.01318	9.873E-5	0.5649	0.5908	0.6166	10001	20000
Theta[3]	0.5328	0.01175	8.413E-5	0.5098	0.5328	0.5558	10001	20000
Theta[4]	0.6216	0.0114	8.142E-5	0.5991	0.6217	0.6438	10001	20000

The analysis was executed with 60 observations for 20000 simulations, a burn-in 10000 and a refresh of 100.

Table 3.2 below shows the posterior distribution of condom use for males. The results indicate that on average males use condoms 68% of the time when having sexual intercourse. It can be observed that in week four the probability that males will use a condom when having sex is 0.7131 with median 0.7132 and a credible interval of (0.6833,0.7423).

Table 3.2 Summary statistics for the use of condoms for males

Nodes	Mean	SD	MC_Error	Val2.5pc	Median	Val97.5pc	Start	Sample
Theta[1]	0.7054	0.01725	1.174E-4	0.6711	0.7057	0.7388	10001	20000
Theta[2]	0.6857	0.01752	1.282E-4	0.651	0.6858	0.7197	10001	20000
Theta[3]	0.6021	0.01629	1.116E-4	0.5706	0.602	0.6338	10001	20000
Theta[4]	0.7131	0.01502	9.709E-5	0.6833	0.7132	0.7423	10001	20000

The analysis was executed with 60 observations for 20000 simulations, a burn-in 10000 and a refresh of 100. Table 3..3 below shows the posterior distribution of condom use for females. The results indicate that on average females use condoms 45% of the time when having sexual intercourse. It can be observed that in week four the probability that females will use a condom when having sex is 0.53 with median 0.5298 and a credible interval of (0.4975, 0.563). It observed that the probability of females' use of condoms is lower than that of males. This exposes females to HIV infections.

Table 3.3 Summary statistics for the use of condoms for males

Nodes	Mean	SD	MC_Error	Val2. 5pc	Median	Vl97. 5pc	Sstart	Sample
Theta[1]	0.4145	0.01861	1.266E-4	0.3781	0.4145	0.4512	10001	20000
Theta[2]	0.4958	0.01894	1.318E-4	0.4587	0.4959	0.533	10001	20000
Theta[3]	0.3645	0.01597	1.072E-4	0.3336	0.3644	0.3957	10001	20000
Theta[4]	0.53	0.01672	1.179E-4	0.4975	0.5298	0.563	10001	20000

Bugs code 3.2 below gives a syntax in which the relative risks of female versus males is calculated. Figure 4 below gives the density distribution of both the hazard ratio and the beta distributions. It can be observed that the density distribution does not include zero. This means there is enough evidence to conclude that there is a significant difference in the use of condoms between males and females among sex workers in Livingstone.

Bugs code 3.2 comparing of females versus males in relative risks in the use of condoms.

```
model

{

# Set up data

for(i in 1:N) {

for(j in 1:T) {
```

```
# risk set = 1 if obs.t > = t
Y[i,j] <- step(obs.t[i] - t[j] + eps)
# counting process jump = 1 if obs.t in [t[j], t[j+1])
# i.e. if t[j] < = obs.t < t[j+1]
dN[i, j] <- Y[i, j] * step(t[j + 1] -
obs.t[i] - eps) * fail[i]
}
}
# Model
for(j in 1:T) {
for(i in 1:N) {
dN[i, j] ~ dpois(Idt[i, j]) # Likelihood
Idt[i, j] <- Y[i, j] * exp(beta * x1[i]) * dL0[j] # Intensity
}
dL0[j] ~ dgamma(mu[j], c)
mu[j] <- dL0.star[j] * c # prior mean hazard
# Survivor function = exp(-Integral{l0(u)du})^exp(beta*x1)
female[j] <- pow(exp(-sum(dL0[1 : j])), exp(beta * 2));
male[j] <- pow(exp(-sum(dL0[1 : j])), exp(beta * 1));
}
c <- 0.001
r <- 0.1
for (j in 1 : T) {
dL0.star[j] <- r * (t[j + 1] - t[j])
}
beta ~ dnorm(0.0,0.00001)
# hazard ratio for female versus male
HR<-exp(beta)
}
# x1 is the gender
list(N=30,T=28,eps=1.0E-10,
obs.t=c(1, 2, 3, 4, 5, 6, 7, 8, 9,10, 11,12, 13,14, 15, 16,17,18,19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29,
30, 1, 2, 3, 4, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30),
fail =c(1,1,1,1,0,1,0,0,0,0,1,1,0,1,1,1,1,0,1,1,0,1,0,1,0,0,0,0,0,
1,1,1,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,1,0,0,0,0,0,0,0,0),
x1=c(2,2, 2, 2, 2, 2, 2,2, 2,2, 2, 2,2 ,2, 2, 2, 2, 2,2,2 ,
2, 2,2,2 ,1, 2, 1, 2, 2, 2, 1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,2,1,1,1,1,1,1,1,1,
```


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1,1,1,1),

t=c(1,2,3,4,5,6,7,8,9,10.11,12,13,14,15,16,17,18,19,

20,21,22,23,24,25,26,27,28,29,30))

initial values

list(beta = 0.0,

dL0 = c (1.0, 1.0, 1.0, 1.0, 1.0,1.0,1.0,1.0,1.0,

1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1 , 1.0, 1.0, 1.0,1.0, 1.0, 1.0, 1.0,1.0, 1.0,1.0, 1.0))

Figure3. 4 below shows the probability densities of the HR and beta distributions and what can be observed is that both densities do not include zero implies there is a significance difference in condom use between males and females

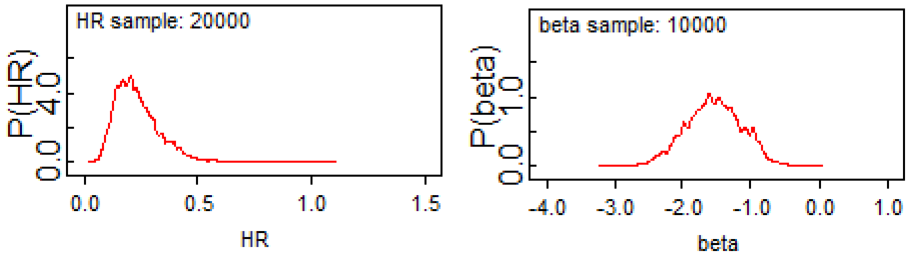

Figure 3.4 The density of hazard ratio and beta distribution

The analysis was executed with 60 observations for 20000 simulations, a burn-in 10000 and a refresh of 100. Table 3.4 below gives the summary statistics of HR and beta. The HR of 0.2342 means there is 76.58% increase in the use of condoms among males. The beta value of -1.541 (see equation 13) is negative means the relative risk of males due to condom use is relatively low as compared to that of females. Note that the credible interval of beta which is (-2.375, -0.7988) means there is a significant difference in the use of condoms between males and females since the credible interval do not include zero.

Table3.4 The summary statistics of hazard ratio and beta distribution for female versus males

Nodes	Mean	SD	MC_Error	Val2.5pc	Median	Val97.5pc	Start	Sample
HR	0.2342	0.09906	0.001955	0.09254	0.2164	0.4661	10001	20000
Beta	-1.541	0.4113	0.01194	-2.375	-1.536	-0.7988	20001	10000

The analysis was executed with 60 observations for 20000 simulations, a burn-in 10000 and a refresh of 100. Table 3.5 below gives the summary statistics of the parameters HR and beta. The HR is 5.197 for males versus females' means the males' use of condoms is five time that of females and the females use condoms 20% of the times they have sex which gives them a high risk of contracting HIV. It is observed that the beta value of 1.544 is positive hence gives them a high risk of getting HIV infection (equation 13).

Table 3.5 The summary statistics of hazard ratio and beta distribution for male versus females

Nodes	Mean	SD	MC_Error	Val2.5pc	Median	Val97.5pc	Start	Sample
HR	5.197	2.402	0.09063	2.11	4.691	11.36	10001	20000
Beta	1.544	0.4028	0.01908	0.7413	1.543	2.372	20001	10000

4. DISCUSSIONS

It should be acknowledged that research on condom use among sex workers has inherent difficulties, current finding along with reported high prevalence rate of HIV in Livingstone indicates infrequent and inconsistent condom use. The probability of condom use on average which is at 0.5755 (58%) it should have made an impact in the reduction of HIV prevalence rate, but this is not the case as Livingstone has a prevalence rate of 23.5% new infections. It is clear from the results that there is evidence of knowledge about the use of condoms as a preventive method against HIV with 58% of condom use. Many factors contribute to the motivation for condom use, and these can only be enhanced individually by changing attitudes and mindset. Despite collecting condoms, its use is challenged by other factors such as negotiation for its use as others claims they do not enjoy sex with condoms, cultural and

religious beliefs. To overcome these barriers, a complete change in attitudes towards condom use and change of mindset is required by sex workers and their clients otherwise the fight against HIV new infection will never be achieved. In this study, female condoms were not popular among females. It was alleged that female condoms are difficult to use especially on non-gentle clients during the act. Efforts should be made to improve the use of female condoms which had low perceived confidence to its utilization; this will help transfer the decision making and control to women so that they contribute to their empowerment and increased protection from unplanned pregnancies, sexually transmitted diseases and HIV infections.

5. CONCLUSION

The results obtained in this research suggest that the use of condom as a preventive method against HIV infection for sex workers should be emphasized on personal vulnerability to HIV especially for females. In as much as it is acknowledged that people know that condoms can be used as preventive methods against HIV infection the method is not useful and has no impact in reducing the HIV infection rate. The use of condoms as an intervention against new HIV infections is faced with many challenges on its use such as infrequent and inconsistency use and other barriers which makes it impossible in reducing HIV new infections. There is a need for government to change peoples' attitudes and mindset on condom use in the nation if this preventive method has to produce positive results.

6. RECOMMENDATIONS

It is clear from the results that many people are aware and have the knowledge about HIV infections and that condoms use is an intervention against HIV infection. It is recommended that government must come up with strategies of how peoples' mindset and attitudes can be changed through the use of condoms as a preventive method of reducing new HIV infections.

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